OptoShield

A Low-Cost Tool for Control and Mechatronics Education

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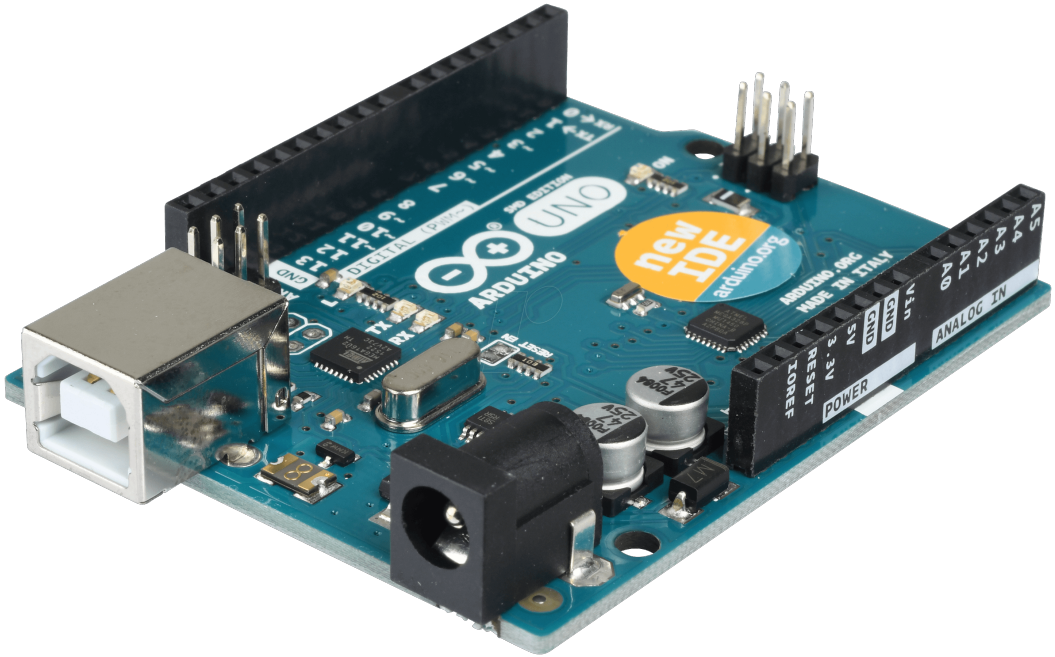
Motivation: Current tools for control education

- Teaching control engineering requires laboratory tools [Bye and Osen 2019]
- Tools are expensive, large, complicated and cannot be taken home
- Many require closed source software (e.g. MATLAB, LabView)
- Implementation on microcontroller units (MCU) is under-represented

Motivation: Arduino—a universal platform to build on

- Cheap
- Open source
- Easy to buy
- Standardized
- Free integrated development environment (IDE)
- Great community and abundance of learning materials
- Easy hardware expansion through "Shields" [Garrigós et al. 2017]



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Create novel tools for control engineering education, implementing a lab experiment on a single Arduino expansion Shield — essentially a "live" mechatronics laboratory in the palm of your hand that is

- Cheap
- Open source
- Possible to build at home even by beginners (DIY)
- Standardized
- Free software library compatible with the Arduino IDE

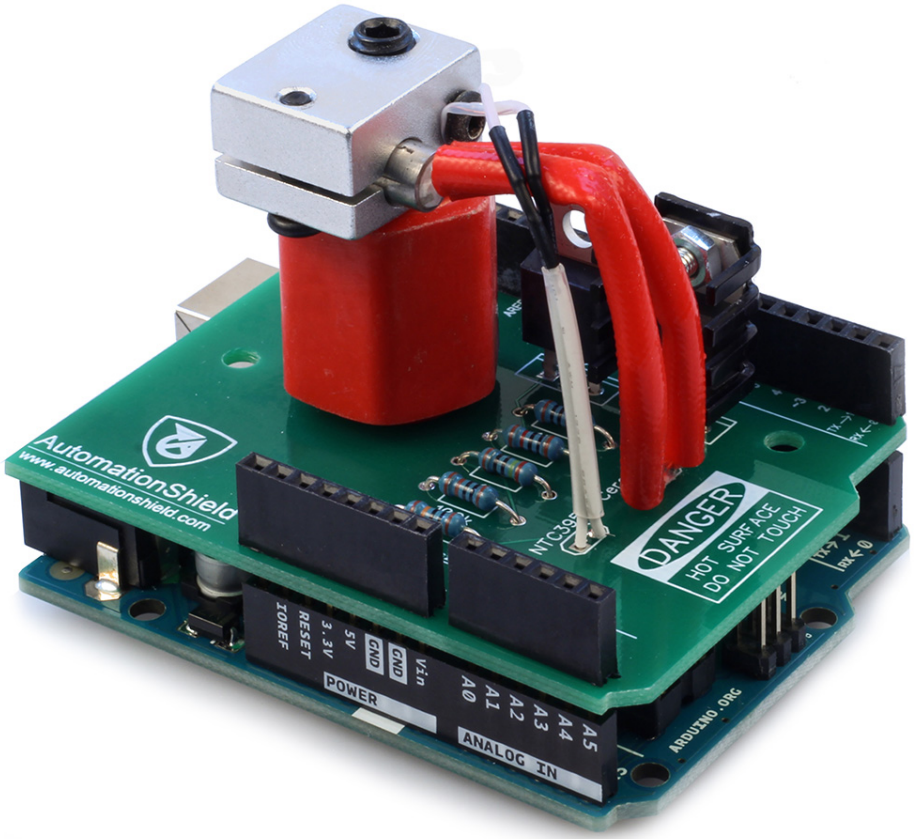
AutomationShield

Control Systems Engineering Education

www.automationshield.com

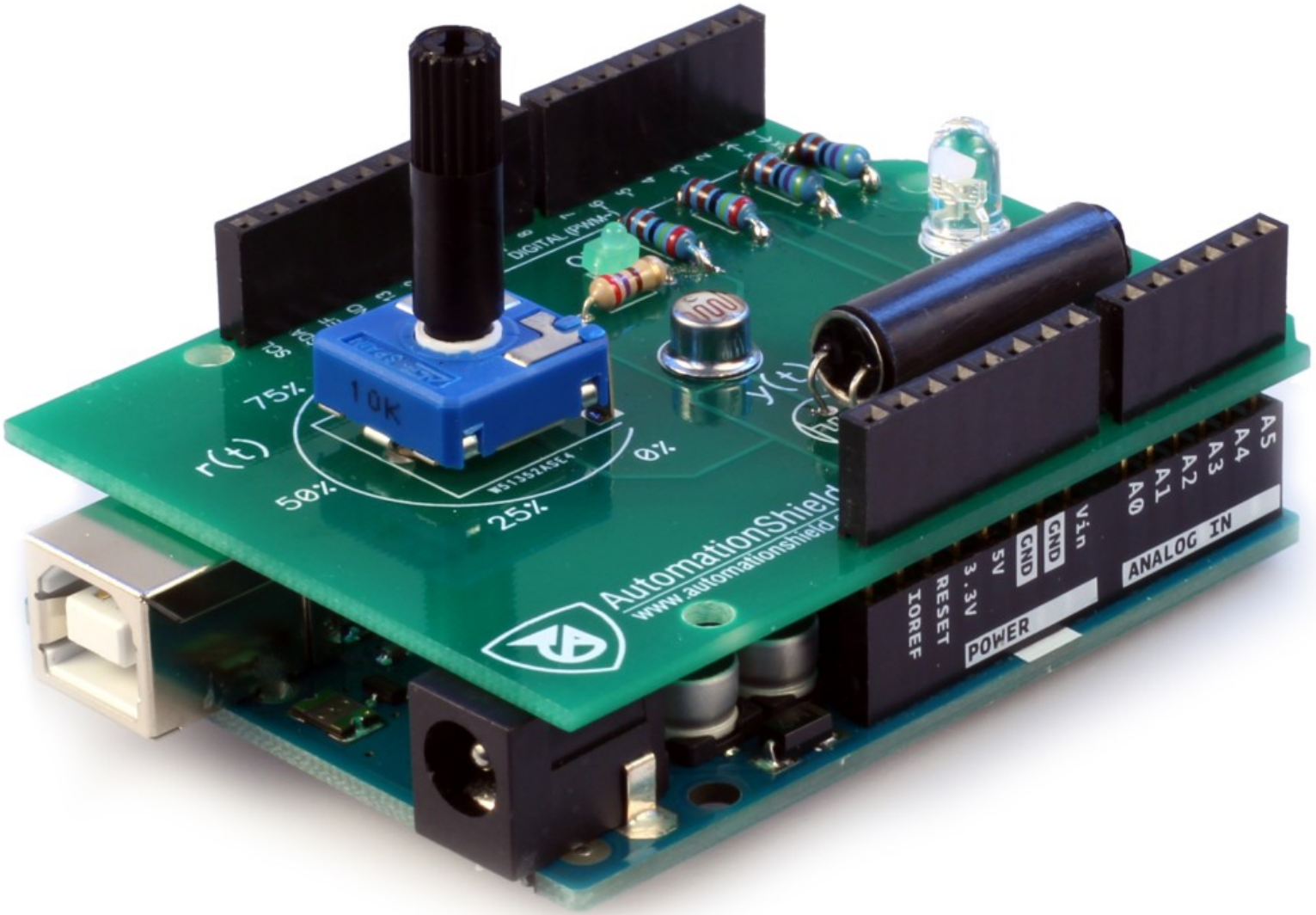
Previous work: "HeatShield"

Filament heating control in 3D printing, presented at EDUCON 2019 (UAE,Dubai)[1]:



[1] Gergely Takács et al. "HeatShield: a low-cost didactic device for control education simulating 3D printer heater blocks". In: *Proceedings of the 2019 IEEE Global Engineering Education Conference (EDUCON)*. Dubai, United Arab Emirates, Apr. 2019, pp. 385–394.

Meet the open-source mechatronics lab in your hands: a simple optical feedback control by the so-called “OptoShield”:



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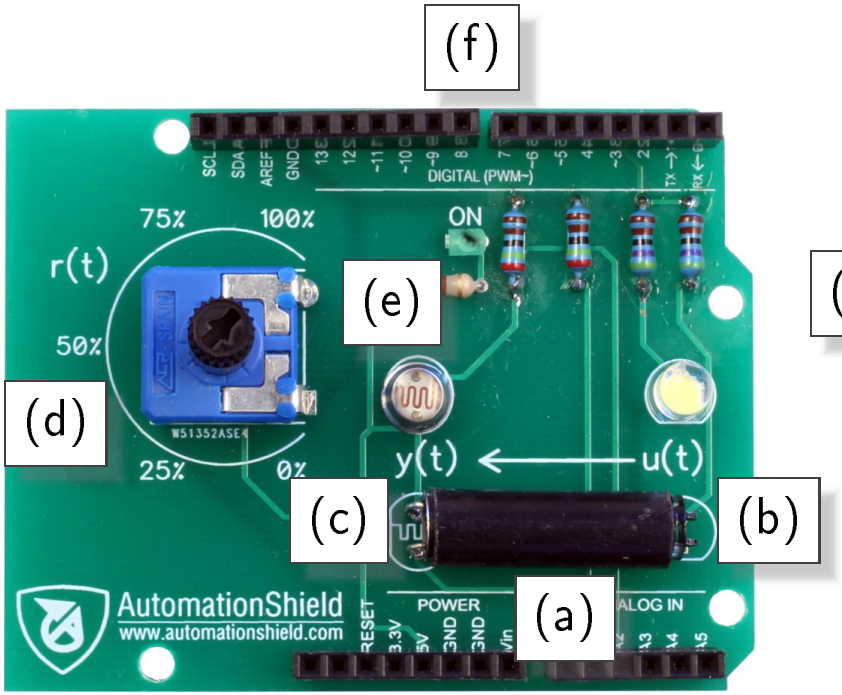
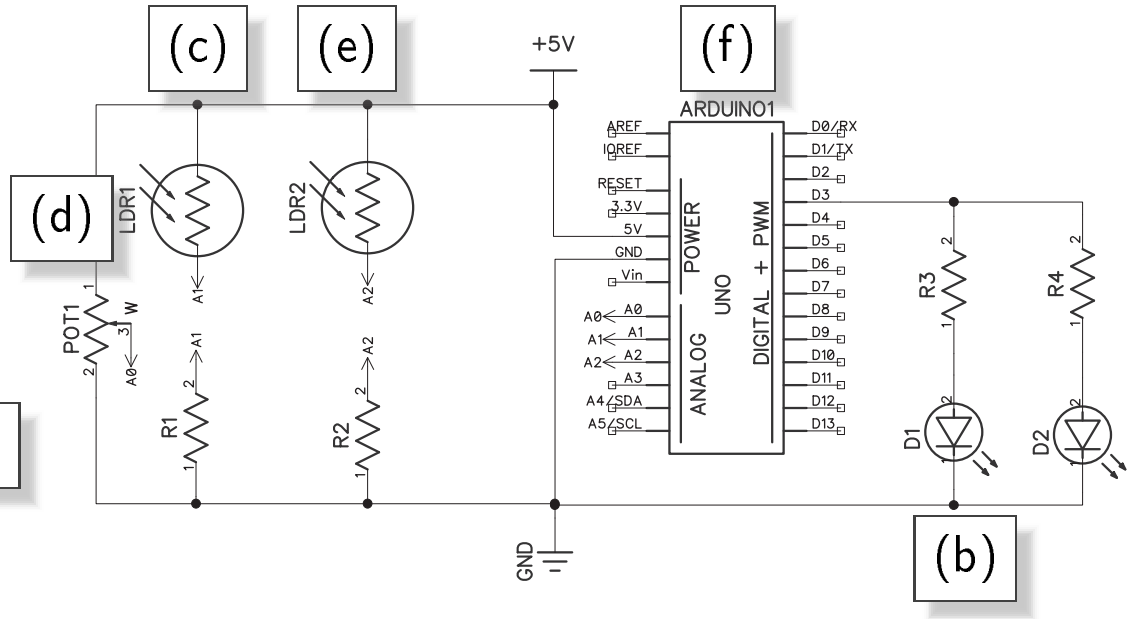


Top view of the OptoShield



Electrical schematics of the OptoShield

(a) Opaque tube
(b) LED
(c) Light dependent resistor (LDR)
(d) Reference pot
(e) Auxiliary LDR (and LED)
(f) Arduino (R3 headers)

Extremely cheap![2]

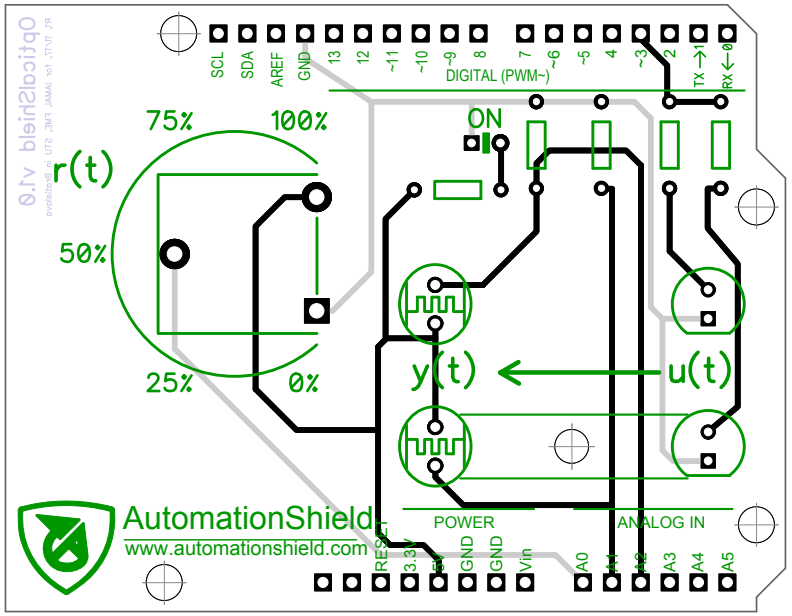
Hardware cost is less than €3 (¥360) per unit, incl. PCB fabrication!

Part	Designator	Pcs.	Price	Sum
LDR, 5 mm, 5–10 kΩ	LDR1,LDR2	2	0.65	1.3
Resistor, 2.4 kΩ	R1, R2	2	0.0074	0.0148
Resistor, 4.7 kΩ	R3, R4	2	0.0074	0.0148
LED 5 mm, clear	D1, D2	2	0.116	0.232
Potentiometer, 10 kΩ	POT1	1	0.2760	0.2760
Potentiometer knob	—	1	0.0920	0.0920
Header 6 pin, F	—	1	0.085	0.085
Header 8 pin, F	—	2	0.096	0.192
Header 10 pin, F	—	1	0.096	0.096
Tube, Φ=5 mm	—	20 mm	0.10	0.10
PCB	—	1	0.50	0.50
Total				€2.9

[2] That is, if you do it yourself. Prices exclude labor. The AutomationShield in a non-commercial project.

- The OptoShield is Open Source Hardware
- Editable schematic plans and PCB layout available along with fabrication-ready production files, including component lists and other details

open source hardware



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An open-source library for the Arduino IDE handles I/O.

Initialize the hardware

```
1 OptoShield.begin();
```

Calibrate output to percents

```
1 OptoShield.calibration();
```

Brightness measurement at the LDR y_k in % related to maximum

```
1 y = OptoShield.sensorRead();
```

Power input u_k to the LED

```
1 OptoShield.actuatorWrite(u);
```

Many more functions in the AutomationShield library e.g. for hard real-time sampling, PID control, etc. All is available on GitHub.

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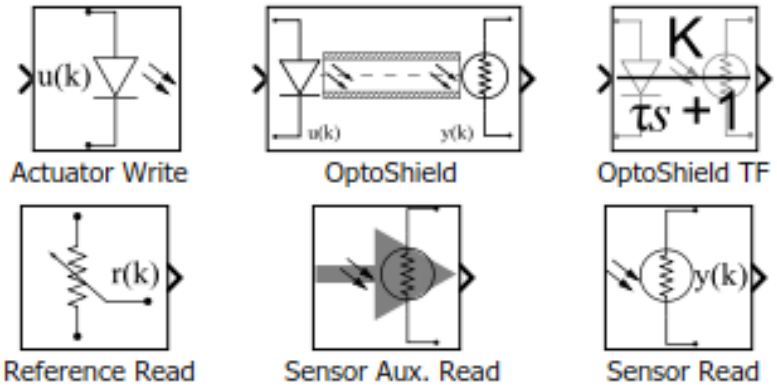
- System dynamics is too fast for the Arduino Support from MATLAB
- Easy-to-use block diagrams in Simulink
- OptoShield is more suited for Simulink where code is compiled directly for hardware
- I/O for individual components, a stand-alone block for I/O representing the device, a transfer function model



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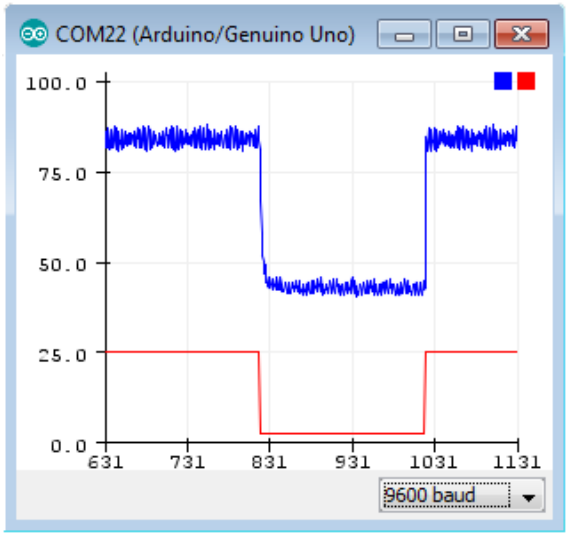
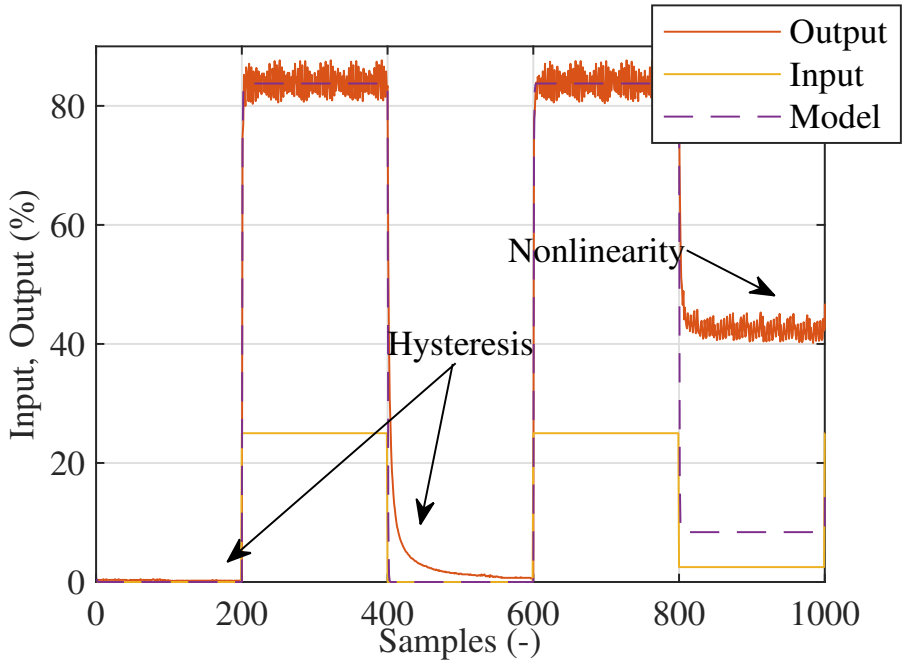
- Experiments to gather input-output data for post-processing, system identification and model validation
- API available in C/C++ for the Arduino IDE
- API available for Simulink



Step response experiment viewed with the Arduino Serial Plotter.



System identification experiment and model verification logged in MATLAB.

Example: PID control (Arduino IDE) I

PID control experiments with user-friendly and built-in sampling and PID functionality. A single algorithm step:

```
1 void step(){                                    // Sample
2 r = OptoShield.referenceRead();                 // ...
      Ref.
3 y = OptoShield.sensorRead();                    // Sensor
4 u = PIDAbs.compute(r-y,0,100,0,100);            // PID
5 OptoShield.actuatorWrite(u);                    // Actuate
6 // [...]                                       // Print
7 }
```

Then use `Serial.print()` to dump results to screen or logger.

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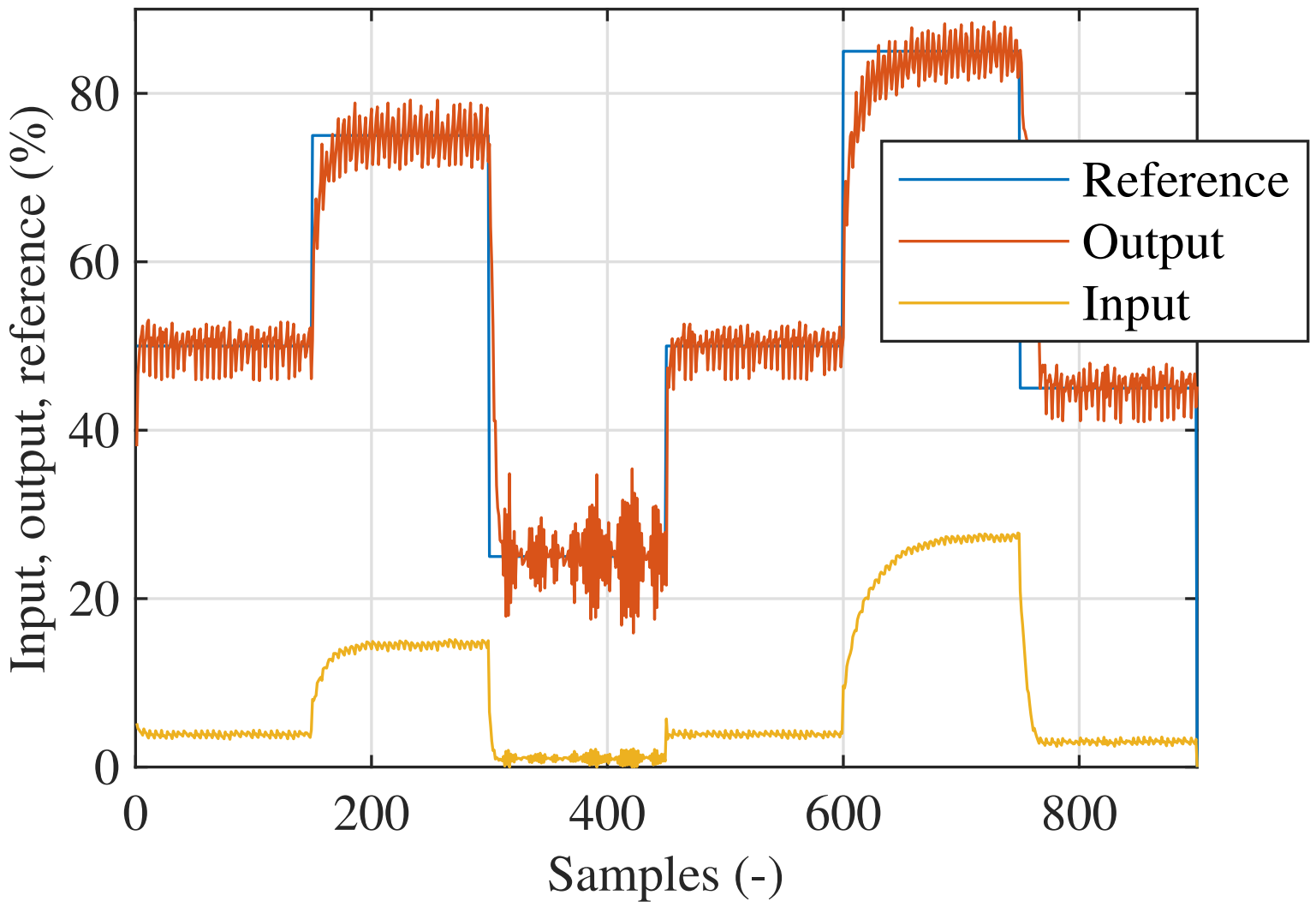
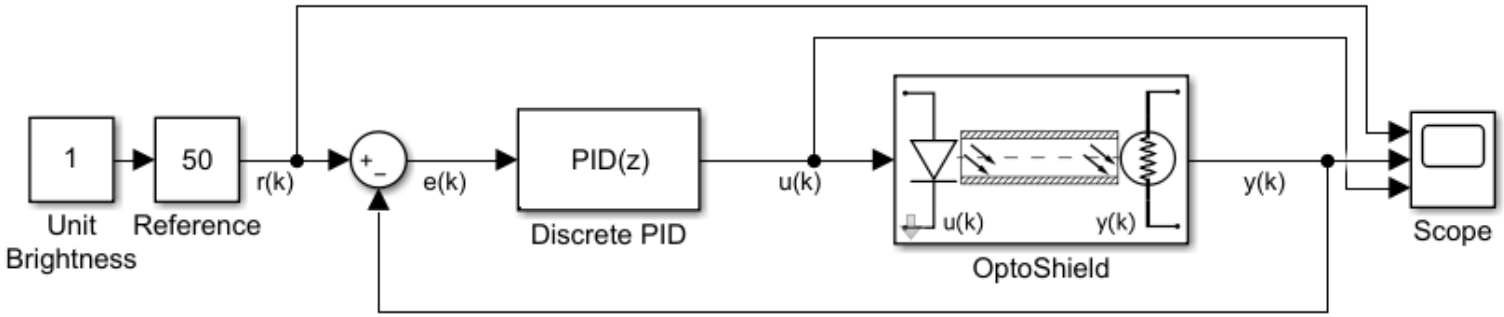
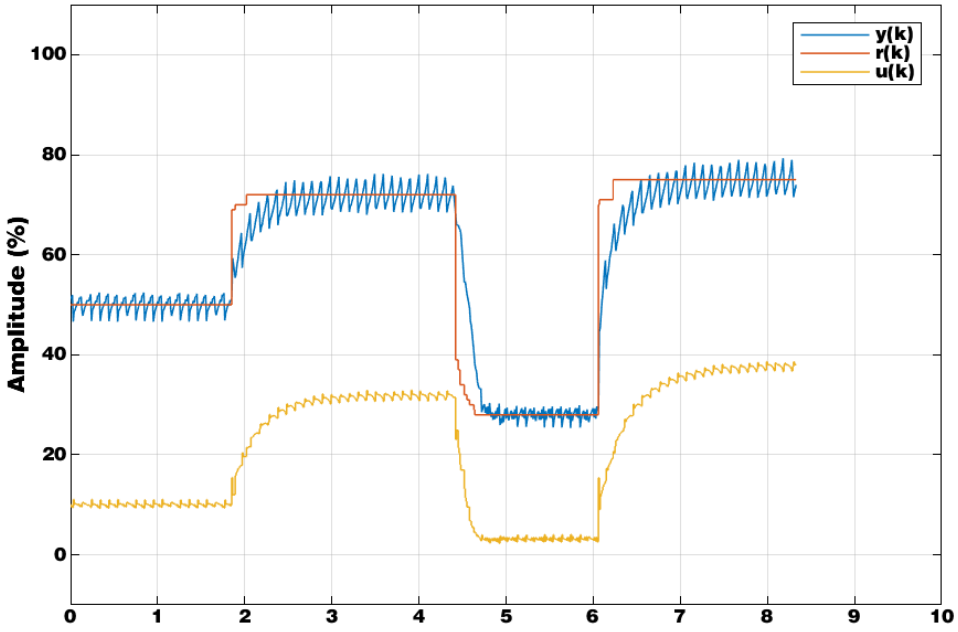


Closed-loop response in the C/C++ API implementation of the PID example.

Example: PID control (Simulink)

"Live" experiments in Simulink with two-way communication with the experimental system. Student can change the reference or tuning and watch what happens on a "Scope":





AutomationShield

- AutomationShield: a non-commercial open-source project for control engineering and mechatronics education
- Full feedback control experiments can be fitted to Arduino expansion modules (lab-on-a-shield)

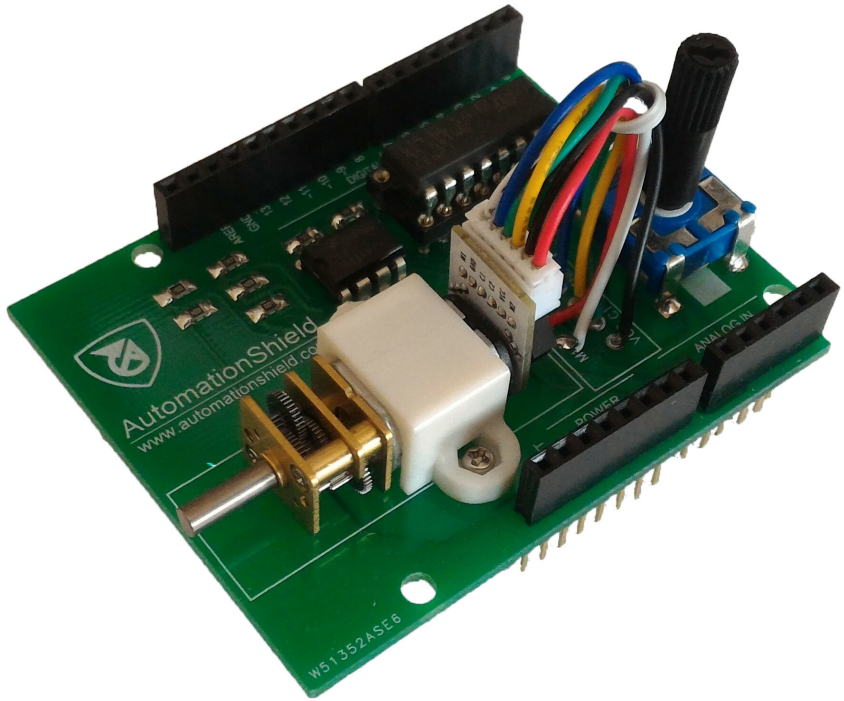
OptoShield

- OptoShield: a simple optical feedback control experiment
- Manufacturing cost is $<$ €5 ($<$ ¥360) - almost "disposable"
- Students can take the "laboratory" home
- Open-source hardware
- Open-source software and examples for Arduino IDE (C/C++) and Simulink

The future: More shields to come

More open-source Arduino Shields for control and mechatronics to come:

Upcoming: "MagnetoShield" A magnetic levitation experiment



Upcoming: "MotoShield" A motor control experiment

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Thank you for your attention!

Make sure to visit `www.automationshield.com` for more information.

Please feel free to contact me any time at
`gergelytakacs@gergelytakacs.com`

References I

Robin T. Bye and Ottar L. Osen. "On the Development of Laboratory Projects in Modern Engineering Education". In: *Proceedings of the IEEE Global Engineering Education Conference (EDUCON)*. Apr. 2019, pp. 1327–1334.

A. Garrigós et al. "Designing Arduino electronic shields: Experiences from secondary and university courses". In: *2017 IEEE Global Engineering Education Conference (EDUCON)*. Apr. 2017, pp. 934–937.

Gergely Takács et al. "HeatShield: a low-cost didactic device for control education simulating 3D printer heater blocks". In: *Proceedings of the 2019 IEEE Global Engineering Education Conference (EDUCON)*. Dubai, United Arab Emirates, Apr. 2019, pp. 385–394.